Section 3.9

Activity Backflow

Contents

BNFL Inc.

Contents

Section 3.9
Activity Backflow from a Process Vessel into the Vessel Wash Cabinet

3.9.1. Work Identification

This example addresses control of hazards associated with the event of an activity backflow into the wash cabinet used for washing V24007, cesium (Cs) and technetium (Tc) storage vessel.

Waste will be pretreated in the Tank Waste Remediation System – Privatization (TWRS-P) pretreatment facility prior to vitrification in the melters. The pretreatment facility provides the stock that feeds the vitrification processes. Waste will be from either the waste supernate (low activity waste envelopes A, B and C) or the sludge (high level waste envelope D) that is currently contained in double-shell tanks on the Hanford Site.

Low activity wastes (LAW), envelopes A, B and C, will be concentrated through a process of evaporation, and filtered prior to ion exchange (Page and others 1998). Cs and Tc will be removed from the LAW waste via ion exchange. If they were to remain in the waste, they would cause the vitrified waste to exceed the limits for allowable concentrations for Cs and Tc. Concentrated Cs and Tc will be stored in the Cs storage tank. HLW (envelope D) will be pretreated to reduce the water content and remove soluble components through a process of filtration and washing. Then the stored Cs and Tc removed from the LAW will be mixed with the HLW and vitrified in the HLW melter.

Plant items in the pretreatment facility will be washed during operations to remove process material and solids, thus reducing activity and preventing a chronic buildup of solids. These plant items are typically vessels, columns, pumps, cell liners and sumps. This example deals only with activity backflow into vessel wash cabinets. The wash liquor may be water or some other suitable aqueous solvent (e.g., dilute nitric acid). The exact frequency of vessel washing has yet to be determined; it will depend on operational and program requirements which will be finalized during the latter part of detailed design. **Open Issue.**

Wash liquor is delivered by a supply line, and distributed by wash cabinets, located in the operations area above the cells. A typical cabinet arrangement is shown in Figure 3.9-1. This example assumes that for each cell there will be one wash cabinet containing multiple connections, one connection serving each vessel. **Design Assumption.** In this example, two or more vessels have been connected to a common supply line during washing (either within the same wash cabinet, or between separate wash cabinets). Due to this condition, the potential exists for process liquor to flow from one of the vessels to the other via the wash cabinet(s). This could occur if the liquid level in one vessel is at a lower level than the other. Process liquor from the vessel with the higher liquor level can be pulled up through the wash line into the wash cabinet piping, through to the other wash cabinet piping and down into the vessel with the lower liquid level. Process liquor flow will continue until the liquid levels in each tank are the same relative to each other. The Cs storage vessel V24007 was selected for this example because of the high activity of the stored Cs requires a more conservative design.

3.9.1.1. Key Process and Design Parameters

3.9.1.1.1. Process

Vessel washing will be performed according to the demands of the operational and maintenance schedule. **Open Issue.** A supply line will deliver wash liquor to wash cabinets located above and outside process cells. Wash cabinets contain isolation valves for the supply of wash liquor for vessel washing. Wash lines run from the wash cabinets, through the walls of the cells, which shield the vessels, and to the wash rings which are within the vessels. Since wash lines run between C3 (wash cabinet) and C5 (process vessel), ventilation system segregation is achieved by the use of a loop (or hydraulic) seal on the line. (See Figure 3.9-1).

Vessel washing will be accomplished by multiple washes, with removal of wash liquids by pneumatic reverse flow diverters (RFDs) between washes. As well as washing the vessel sides, it will also be possible to fill the vessels to their working levels to allow soaking.

3.9.1.1.2. Cs Storage Vessel V24007 Design

V24007 stores the Cs and Tc solutions arising from the Ion Exchange process. The material at risk (MAR) within the Cs storage vessel is based on the total Cs and Tc inventory arising from the pretreatment of 241-AZ-101 and 241-AZ-102. The total volume of Cs/Tc solution is currently estimated to be 45 m^3 (**Design Assumption**) and the total activity (decayed to 2008) is 8.5 MCi. This basis leads to a Cs-137 (the dominant radionuclide) storage concentration of 189 Ci/L.

The Cs storage vessel is a cylindrical vessel with dished ends that will hold Cs and Tc in a 6M nitric acid solution. The vessel sizing will allow storage of all Cs and Tc resulting from pretreatment for two years. After this time, the high level waste (HLW) vitrification line is expected to be operable and will begin processing the Cs and Tc solution (Page and others 1998). The Cs storage vessel allows for confinement, mixing and sampling of the Cs and Tc nitrate solution.

The vessel and all of its internal components will be constructed of stainless steel (304L). **Design Assumption**. Vessel internals include cooling coils, pneumatic reverse flow diverter (RFDs) pumps, and pneumatic pulsed jet mixers (BNFL Inc. 1998i). The vessel design also includes an internal wash ring to allow decontamination of the vessel internals.

The maximum operating volume of V24007 is 56.2 m^3 (BNFL Inc. 1998i) and the total volume is 63.02 m^3. **Design Assumption**. The vessel diameter is 3,700 mm and it is 6,500 mm high (BNFL Inc. 1998i)

3.9.1.1.3. Wash Ring Design

Wash rings are provided to spray wash water onto the vessel walls. Wash rings are generally located above the maximum working level of the vessel (40 to 85 mm below the top of the vessel) and 40 to 150 mm from the walls. The walls, top and top-dish weld of the vessel are washed with a wetting action (not pressure jetting) to aid in removal of solids from the walls (BNFL Inc. 1999). Wash rings may also be submerged to provide greater agitation of sediments in the tank as an aid in their removal. Submerged wash rings create a potential for backflow of active liquid out of the vessel through the wash ring and wash line. This example recognizes that the final TWRS-P design may employ submerged wash rings in some of the vessels. **Design Assumption.**

In accordance with the BNFL Inc. *Design Guide of Plant Wash Operations* (BNFL Inc. 1999), wash rings generally have three holes of 2.25-mm diameter at 75-mm pitches – repeated along the circumference of the ring - and four holes for draining. The general rule of thumb is that the wash ring cross-sectional area equals approximately (2) x (the total hole area).

To avoid high-pressure drops and achieve satisfactory spray performance, if a wash ring is greater than the 50-mm nominal size, then it will be split into two or more segments, with each segment supplied by a dedicated wash line. A flow rate of 2.5 m^3/h for each meter in the vessel wall's circumference will be used for the design of the wash ring, giving an anticipated wash liquor flow rate of 30 m^3/h to the Cs storage tank. Orientation of wash holes on the ring/segment and wash-jet impact distances will be confirmed at the detailed design stage. **Design Assumption**.

3.9.1.1.4. Wash Cabinet Design

BNFL Inc. has standard designs for 7-, 9-, 10-, 16- and 20-connection point, permanently piped, wash cabinets. Project-specific wash cabinets may be identified, but standard design features will be used (BNFL Inc. 1998d).

Wash cabinets provide the means to feed and distribute wash liquors to process piping and equipment, and provide sustainable containment for the out-of-cell demountable connections (e.g., flanges, couplings, and valves). They also ensure safe access, operation, and maintenance of the associated wash equipment within the confines of the cabinet (BNFL Inc. 1998d). Wash cabinets will be located outside the cell, typically above the cell roof (BNFL Inc. 1998c).

3.9.1.2. Interfaces

3.9.1.2.1. Cs Storage Vessel V24007

The Cs storage vessel interfaces with the Cs and Tc concentration systems in the cesium removal and nitric acid recovery cell and with the technetium removal cell, from which it receives its feeds. The vessel, which supplies the Cs and Tc feed, in turn interfaces with the HLW blending vessel.

The vessel is connected to the process vessel vent system which removes vapors, aerosols and other gases evolved from the vessel contents, and maintains the internal pressure of the vessel slightly negative to the surrounding cell.

The cell walls have penetrations to accommodate process, reagent, and service lines (wash liquors, compressed air, etc.) to V24007. Where lines originate from outside the cell (from reagents and services), stepped (pipe toggle) penetrations via wall or floor-boxes are used (See Figure 3.9-1). This ensures that there is no direct radiation shine path from the active cell, along the route taken by the piping from the inactive (out-of-cell) areas, and into the active process cell.

The C5 ventilation system provides confinement and containment of contamination by maintaining the cell at a pressure that, while nominally atmospheric, is slightly negative to the operations area (BNFL Inc. 1998e).

The vessel is connected by the wash lines to the wash cabinet located in the operations area above the cesium removal and nitric acid recovery cell (BNFL Inc. 1998c). The cabinet contains the isolation valves that feed and distribute wash liquor to the Cs storage vessel, and other vessels in the cell. The wash lines run from the cabinet, penetrate the walls of the cell, and pass through a loop seal prior to entry into the vessels. Each vessel wash ring has at least one dedicated wash line (BNFL Inc. 1998d).

The wash cabinet is connected to the C3 ventilation system to maintain the internal pressure nominally atmospheric and slightly negative to the operations area (BNFL Inc. 1998e).

A supply line in the operations area (14 m elevation) will deliver demineralized water or process water or other wash liquors to the wash cabinets. One or more isolation valves at manifolds in the operations area will be used to control the flow of wash water to the cabinets (BNFL Inc. 1998c).

Ventilation systems, and associated equipment for the pretreatment facility, will provide containment and confinement of contamination, remove airborne particulates from discharge air to ensure emissions are within the prescribed limits, and provide a safe working environment for personnel and equipment. These ventilation systems are based on the cascade principle, with the direction of airflow from areas with low and no contamination into areas of potentially higher contamination. This results in a pressure gradient across in-cell vessels, cells, and the operating areas, such that in-cell vessels experience the lowest pressure relative to the operating area. Cascade ventilation and high-efficiency particulate air (HEPA) filtration will ensure minimal dose uptake to the worker and minimal radioactive discharges to the environment (Page and others 1998).

3.9.1.2.2. Radiological Monitoring

Continuous Air Monitors (CAMs) and Area Radiation Monitors (ARMs) will be installed at strategic locations throughout the pretreatment facility. CAMs and ARMs will warn workers of exposure to radioactivity above prescribed limits, and mitigate the total dose to the worker by prompting evacuation and reducing the duration of worker exposure (Page and others 1998).

3.9.1.3. Operating Environment and Setting

3.9.1.3.1. Setting

Preliminary building layout drawings for the pretreatment facility (BNFL Inc. 1998b) indicate that there are 43 vessels and 10 columns located in 8 cells. Although the washing mechanism is different (spray nozzles in columns, and wash rings in vessels), both receive wash water from wash cabinets. For this example it is assumed that the potential for activity backflow into wash cabinets exists for all vessels and columns. **Open Issue.**

Cs storage vessel V24007 will be located inside the cesium removal and nitric acid recovery cell in the pretreatment facility. The floor of the cell is at the –14 m elevation, and the top of the cell is at the 14 m elevation. The Cs storage tank is located at the –14 m elevation (BNFL Inc. 1998b, 1998c).

The cell has thick concrete walls that provide radiation shielding to workers. The walls and floor of the cell are lined with stainless steel (**Design Assumption**) to assure secondary confinement in the event of a leak of one of the vessels in the cell. The cell floor slopes to a collection sump which contains equipment for leak detection, washing and emptying. The stainless steel lining is designed to contain at least the volume of the largest vessel in the cell (Page and others 1998).

3.9.1.3.2. Operating Environment

The wash cabinet is located in the operating area above the cell and will be subjected to ambient temperature and pressure of the building atmosphere in the C2 areas. Since the cabinet may be used to supply nitric acid wash liquor it should be fabricated from suitably compatible materials, with provision for collection and drainage of spillages. Similarly, because of the potential for backflow of activity via the wash lines to the vessels, the atmosphere of the cabinet may contain radioactivity under fault conditions. The cabinet internals (pipework, valves, couplings, etc.) will be exposed to the pressure of the wash liquor and nitric acid supply systems and under fault conditions to the vessel ventilation depression and environment.

3.9.1.4. Applicable Experience

Plant Wash Services similar to those intended to be used in TWRS-P have been in use for many years in BNFL's operational facilities at the Sellafield Site. They provide the operational flexibility to reduce, purge, or clean radioactive constituents from the process vessels. These services are useful in deactivation and decommissioning activities as well as supplying an intermediate clean-out capability for facilities, processes, or vessels.

Provision for Plant Wash Services is included in the design of the facility, both internal and external to the process vessel. For large tanks it is typical to have plant wash rings located above the maximum operating tank liquor level, ensuring that the internal walls are wetted and cleaned thoroughly during the washout operations. Plant wash liquor is introduced to the process vessel via plant wash lines. The plant wash lines are located within the operating area in suitable secondary containment, be that a cabinet or glovebox (dependent on the potential for contamination).

The wash cabinets may be fitted with suitably valved, permanently connected manifolds or flexible hoses fitted with snap-on self-sealing couplings that the plant operator must connect. In some cases the permanently installed manifolds may be fitted with motorized valves and operated remotely, but in most instances plant wash operations are carried out manually. Whether automatic or manual, plant wash operations are carefully detailed in approved and validated procedures and executed by suitably trained operators.

A number of design safety features are incorporated into the Sellafield facilities to prevent the backflow of activity from process vessels to the wash cabinets via the wash line. These include:

- Locating the cabinets a full barometric head above the process liquor level
- Locating wash rings above the maximum liquor locating level in the vessel
- Using 3-way valves which vent the wash line when washing is complete
- Fitting loop (hydraulic) seals in the wash lines.

Additionally, the cabinets themselves are designed to provide secondary containment and ventilated either via the C3 or the C5 ventilation system. Depending upon the contamination potential operator access may be via glove ports or doors.

In the older plants where the wash facilities do not have some of the design safety features listed above, backflow of activity has occurred under various fault conditions. In all instances, the investigations have been able to establish the cause and the events would have been prevented if the suite of controls now in use were to have been in force then. Thus, the use of out-cell wash cabinets is a well-understood technique and mature, effective control strategies that have been developed to prevent backflow of activity.

Hanford operating practice is to isolate process vessel activity from reagent (or other) services that originate out of cell by the use of seal pots (loop seals) or a positive airflow through the line into the vessel.

3.9.2. Hazard Evaluation

3.9.2.1. Hazard Identification

The Part A HAR (BNFL Inc. 1997) dealt with potential activity backflow into the cold chemical feed systems located out-of-cell but serving in-cell process vessels. The potential for migration of activity up the chemical feed lines via the mechanisms of diffusion, pressurization (suction), and siphoning was recognized. Since only low consequences were estimated for those systems under consideration, no further evaluation took place. This was in accordance with the guidelines in the ISAR (BNFL Inc. 1998).

Systematic hazard identification studies conducted on Sellafield facilities employing similar systems have also identified the potential for activity backflow. Use of the information in the HAR and the Sellafield experience shows that activity could become present in a wash cabinet in the following ways:

- Pressure buildup in dipped lines during vessel filling or due to gas buildup
- Pressurization of the vessel
- Overfilling leading to material forced up wash lines due to overfilling
- Siphoning between vessels when connected to the same wash liquor supply line
- Migration (diffusion) of radioactivity through liquid trapped in the wash line, or as airborne activity if no hydraulic seal is present.

The potential for other mechanisms will be further assessed when detailed design has progressed enough to do a rigorous Hazop II study.

Siphoning between vessels can occur as a result of a single failure – closure of the main supply valve while washing operations are being conducted in two vessels.

Overfilling is considered unlikely to result in liquor transfer to the cabinet because of the provision of adequate overflow protection.

Vessel pressurization is also less likely than siphoning to result in significant quantities of liquor getting back to the cabinet because it would require simultaneous failure or blockage of the vessel ventilation system as well as a pressurization event sufficient to drive the liquor up to the cabinet

Pressurization of vessels and overfilling vessels will be subject to a more comprehensive hazard analysis when the detailed design information (i.e., as presented in the P&IDs) is available for all of the vessels and their supporting services. **Open Issue.**

The other mechanisms would only result in relatively small amounts of activity backflowing to the cabinet and the consequences would be very much less than the siphoning event. Hence, these events will not be analyzed further in this example.

Although the potential for worker contamination exists from a coincident failure of the service cabinet pipework or connections during vessel washing operations, it will not be considered any further in this example. This is because three further independent and coincident failures are required. In addition to the siphon event, there would have to be a line breach, connection failure, and the operator would have to have breached wash cabinet confinement. Although the consequences of a potential contamination event may be onerous, the initiating event frequency will be low in comparison with the siphon event. Further work will be carried out on this scenario as part of the detailed hazard identification and assessment work that will accompany the Part B-1 detailed design work. **Open Issue.**

Siphoning of process liquor into the wash cabinet wash lines as a result of misvalving wash liquors leading to a direct radiation dose to the worker is chosen as the hazardous event for further evaluation. It offers a potentially high frequency, high consequence event against which a suitable control strategy can be developed.

3.9.2.2. Event Sequence

The postulated sequence of events that could potentially lead to siphoning of radioactive material into the wash line is:

- Two vessels at different heights and/or differing liquid levels are connected to the wash header via valves in wash cabinets at the same time.
- Washing is started and the lines are filled, supplying wash liquor to the vessels.
- The wash water supply is isolated at the manifold input valve on the supply line (operator error).
- Radioactive material is siphoned from the tank with the higher liquor level through the wash line into the tank with a lower liquor level.

The potential for this hazard is not limited to tanks in the same cell. Since there will be other wash cabinets connected to the same supply line, the same sequence of events could lead to siphoning of material between different wash cabinets upon closure of the manifold input valve.

3.9.2.3. Unmitigated Consequences

The unmitigated consequences were estimated as 836 rem (facility worker) and 9 rem for the co-located worker, assuming a 2-hour exposure time for the facility worker. **Design Assumption**.

The worst-case consequence would occur if the material were being siphoned between separate wash cabinets because there would be more affected piping, capable of holding more material and affecting a wider area, than would be expected during backflow between two tanks connected to the same wash cabinet. Therefore, to determine the worst-case consequence, the following assumptions were used:

- The waste that provides the highest gamma ray exposure is involved.
- The unshielded wash line, with a diameter of 50 mm, will have a length of 4m inside an unshielded wash cabinet, with an additional length of 126m outside of the cabinet.
- There is no attenuation of radiation due to wash line or cabinet wall thickness (mitigation).
- There is no credit taken for area radiation alarms (mitigation).

A 130-meter length for each wash line was assumed because this would be the worst-case scenario involving two tanks located at opposite ends of the pretreatment facility.

The estimated dose was calculated for a facility worker and co-located worker (BNFL Inc. 1999c). In both cases, the exposed worker was assumed to be at the specified distance from the wash line and in a position to receive the highest dose rate. A one-meter distance is reasonable because the worker is outside of the wash cabinet and the affected portion of the wash line external to the cabinet would most likely be located overhead. In accordance with BNFL Inc. code of practice (BNFL Inc. 1998g) the co-located worker is assumed to be at the point of maximum dose and a minimum of 100 meters from the facility. Also in accordance with the BNFL Inc. code of practice, exposure to the public from "direct radiation shine" is not calculated because the nearest point of public access is estimated to be over 9 km south-southwest from the facility along Highway 240. The amount of material in the tank was assumed to be its maximum inventory decayed to the year 2008 (BNFL Inc. 1999c) which gives the following concentrations for the 45 m^3 (45 x 10^3 liters) tank volume:

- ^{134}Cs 1.69 x 10 $\mu Ci/cm^3$
- ^{137}Cs 1.89 x 10^5 $\mu Ci/cm^3$
- ^{137}Ba 1.89 x 10^5 $\mu Ci/cm^3$
- ^{99}Tc 3.78 x 10 $\mu Ci/cm^3$

The volume of material in the 130-m length of 50-mm diameter wash line is approximately 263 L [Note: 3.14 x $(2.54\ cm)^2$ x 13000 cm x $10^{-3}\ L/cm^3$) = 263L].
The unmitigated consequences and severity level are estimated to be (BNFL Inc. 1999c):

Unmitigated Dose Consequence

Exposed Person	Distance (m)	Dose (rem)	Severity Level[1]
Facility Worker	1	836	SL-1
Co-located Worker	100	9	SL-2
Public	Not significant due to distance to nearest point.		

1. See Category 2 Information Introduction

Based on the calculated dose rate (418 rem/h), a siphon would have to occur for only a few minutes with a worker standing close by (1 m) for the severity level to be SL-1.

It should be noted that this source term is pessimistic since it assumes an activity level associated with process liquor alone. Washing V24007 will take place after the vessel has been emptied of process liquor to low level. Hence the first addition of wash liquor will dilute the remaining heel of process liquor and so any potential siphon event at this time would involve diluted process liquor with a consequent decrease in the source term to that assumed above. However it is considered that even dilute process liquor siphoning through wash cabinet piping is likely to give a radiation dose which may exceed 25 rem (but far less than 836 rem) to the facility worker and so the conclusion that this event is a SL-1 hazard is valid.

3.9.2.4. Frequency of the Initiating Event

The frequency of the initiating event will depend on the frequency of tank washing, which has not been finalized. **Open Issue**. For the purpose of this example, annual tank washing is assumed. This applies to the operation of washing a single tank or two or more tanks at the same time. **Operational Assumption**.

Quantification of the event sequence (3.9.2.2)

Event	Frequency/y	Probability	Basis
Wash operation on V24007	1.0	N/A	Operational assumption
One (or more) other tanks being washed at the same time	N/A	1.0	Operational assumption
Operator erroneously shuts off main (wash liquor) manifold valve serving the two wash cabinets that are connected to the process vessels through the open wash line valves within the same (or different) wash cabinet(s). This isolates the wash liquor supply but leaves wash lines and interconnecting piping still open to process vessels. Potential for siphon condition.	N/A	3.0×10^{-2}	Technique of Human Error Prediction (THERP)[1] analysis which takes no credit for training or procedures.

[1] US NRC, 1983

The initiating event frequency for the siphoning hazard is given as:

$$1.0/y \times 1.0 \times 3.0 \times 10^{-2} = 3.0 \times 10^{-2}/y.$$

3.9.2.5. Common Cause and Common Mode Effects

The common cause or common mode effects identified as most likely to be a significant contributor to the accident frequency were human error and loss of power. This is directly assessed in the development of the control strategy.

If the wash cabinet is automatically operated, loss of power could initiate the hazard if it were to occur during simultaneous tank-washing of V24007 and another process vessel, causing the manifold valve to shut (as opposed to having the valve shut through operator error). The probability that a loss of power will occur during the 2-hour wash period is estimated as 1.1×10^{-5}. This figure is based on applying a 2-hour wash time to the average value of 5.7×10^{-6} /h outage rate for all U.S. utilities (NRC 1998).

The frequency of the siphoning event due to a loss of power is the frequency of washing multiplied by the probability of simultaneous washing of tank V24007 and another vessel multiplied by the probability of the loss of power during that time. This is:

$$1.0/\text{y} \times 1.1 \times 10^{-5} = 1.1 \times 10^{-5}/\text{y}.$$

This is low compared to the frequency of the operator initiated event of 3.0×10^{-2}/y. A separate control strategy against the contingency of loss of power will not be considered further for this example. Loss of power will be considered explicitly as part of the hazard identification and assessment work that accompanies the Part B-1 design. **Open Issue.** Loss of power will not be considered further in this example.

3.9.2.6. Natural Phenomena Hazards and Man-Made External Events

3.9.2.6.1. Natural Phenomena

Natural phenomena hazards (NPH) and their treatment on a plant-wide basis is addressed in Section 2.10. None require addressing uniquely in developing this control strategy. It is not considered credible that the NPH could initiate the hazard and no credible mechanism has been identified by which the NPH could increase the consequences of the event even if the NPH were to occur coincident with the hazard.

3.9.2.6.2. Man-Made External Events

Similarly, man-made external events and their treatment on a plant-wide basis are discussed in Section 2.10. With the exception of causes of loss of power there are no man-made hazards that could uniquely affect this event.

3.9.3. Control Strategy Development

3.9.3.1. Controls Considered

The control strategy needs to address the initiating events which can lead to the hazard of radiation dose to the facility worker due to process liquor in wash cabinet pipework. Two events are estimated to give rise to a frequency of 3.0×10^{-2}/y:

- Requirement to wash vessel V24007 and another process vessel at the same time.
- Operator error in closing main manifold valve, leaving two wash valves open.

The consequences of the hazard are SL-1 to the facility worker. This is considered to bound the consequence of SL-2 to the co-located worker since the control strategy will afford equal protection to both facility and co-located workers.

The following control strategies were considered to prevent or mitigate the consequences of a backflow of the Cs storage tank into a wash cabinet during tank washing:

- Wash Ring above Maximum Operating Liquor Level of Tank. Locating the wash ring(s) above the maximum operating level of the tank would maintain an air gap and preclude a backflow event due to siphoning, or greatly reduce the amount of material in the backflow to what is above the wash ring(s) in the case of an overfill situation.

- Barometric Head Protection. A barometric head is the height of a column of liquid under absolute vacuum. The height is dependent on the liquid density. In the case of water, it is 10 m. This assumes no other motive force such as a pump or a mechanism which might decrease the liquid density such as aeration. There is no such pump in the wash line to V24007 and no aeration mechanism has currently been identified. Therefore, if the vertical distance between the top of vessel V24007 and the bottom of the wash cabinet is ≥10 m, then there is no mechanism that would lift the process liquor from the tank and cause a backflow up the line. Locating the wash cabinet greater than the barometric head above V24007 precludes the initiation of a backflow due to siphoning. Siphoning is not a credible event in a facility employing barometric head protection.

- Loop (Hydraulic) Seals. Maintains separation between the vessel vent and the C3 vent in the wash cabinet, preventing airborne activity backflow.

- Radiological Monitoring and Alarms. ARMs alert workers to exposures that exceed prescribed limits and mitigate the total dose received by limiting the amount of time workers are exposed during a backflow event.

- Wash Cabinets with Only One Connection Off Header. The initiation of a siphon event is contingent upon connecting two or more tanks or vessels to the same header. Employing a single, flexible valve or interlocked valves in each cabinet prevents connecting two or more tanks within the same wash cabinet to the same header. This assumes that there would be a single cabinet for each process vessel.

- One-Way (Non-Return) Valves. Installing one-way valves in the wash lines prevents the backflow event by stopping the flow of materials between the tanks and the isolation valves.

- Provision of Three-Way Valves on the Supply Manifold and the Individual Wash Lines. This arrangement would have a wash feed position and vent position. The wash feed position would allow wash liquor to flow from the manifold through the wash cabinets and into the process vessel. The vent position would allow the wash liquor lines to be vented, thus preventing liquor holdup in the wash liquor feed lines. Wash liquor would drain through the loop seal back into the process vessel.

- Administrative Controls. Approved procedures specify the required actions and sequence for washing tanks. The correct sequence reduces the likelihood connecting two or more tanks to the same supply line at the same time. Approved procedures also provide evacuation alarm response training. Prompt evacuation mitigates the total dose received by limiting the amount of time the workers are exposed during a backflow event.

- Siphon Breaks. Installing siphon breaks (such as high point vents, air inbleeds, or poppet valves that open on reduced pressure) on the wash lines prevents siphoning by venting the wash line during the initiation of a backflow.

- Shielding. The use of shielding in the wash cabinets and on the wash lines mitigates the total dose a worker receives by limiting the amount of radiation exposure.

- Automated Washing Systems. The use of permanent piping remote controls and remote displays, all of which increase the distance between the worker and the affected wash cabinet, reduces the risk to the worker during a backflow event.

3.9.3.2. Control Strategy Selected

Control strategy selection was based on a two-step process: first, clearly unrealistic control elements were deleted; second, engineering tradeoffs were considered to further down-select the options, and a preferred control strategy was selected.

3.9.3.2.1. Initial Screening (Step 1)

The merits of each of the potential controls described above were considered, primarily against the following set of criteria:

- Effectiveness

- Practicability

- Reliability

- Demonstrability

- Compliance with laws and regulations

- Ability to comply with DOE/RL-96-0006, *General Radiological and Nuclear Safety Principles* (in particular, use of proven engineering practice, ease of providing inherent/passive safety features, radiation protection features, and avoidance of undue reliance on human actions).

The objective of this review was to identify the main advantages and disadvantages of each control, and also to eliminate those which were not considered viable in formulating a composite control strategy. The results of the process are shown in the following table.

Table 3.9-1. Initial Evaluation

Control	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Wash Ring above Maximum Operating Level of Tank	A passive control that uses an air gap in the tank to prevent the formation of a backflow A simple and highly reliable control	Wash ring will not agitate sediments in the bottom of the tank Does not protect against overfilling	Yes	Yes – although an effective control, it may not be practical to implement in all cases because wash rings at low levels increase the ability for solids removal by providing additional agitation. Can be used in conjunction with other elements of the control strategy.
Barometric Head Protection	A passive control Siphoning is not a credible event in a design that includes barometric head protection It is highly reliable, simple and eliminates the hazardous event	May impact on cell and facility layout by increasing cell sizes and requiring additional pipework	Yes	Yes– good simple, passive feature.

Table 3.9-1. Initial Evaluation

Control	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Loop (Hydraulic) Seal	Simple, active protection	Ineffective – does not provide protection against this event	Yes	No – but included since it provides protection against backflow of airborne activity
Radiological Monitoring and Alarms	Mitigates the total dose received by the worker by reducing the exposure time Effective and demonstrable in providing the mitigative element in the control strategy The overall reliability of area monitoring equipment will be calculated during detailed design work. **Open Issue**	Does not prevent or mitigate an actual backflow event	Yes – depends upon operator actions	Yes – not developed as a result of this control strategy since already present It may be credited within this strategy
Wash Cabinet with Only One Connection Off Header	Prevents connection of tanks within the same wash cabinet to the same supply line	Does not prevent connection of tanks in separate wash cabinets to the same supply line Not effective in either preventing or mitigating the hazard Costly	No	No

Table 3.9-1. Initial Evaluation

Control	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Venting of Wash Lines and Manifold on valve Closure – Provision of 3-way Valves	Prevents the potential for a backflow (siphon) event Active protection that is simple, reliable and easily maintainable (positioned out-of-cell, within the wash cabinet)	Relies on administrative controls alone for its effectiveness	Yes	Yes
One-Way (Non-Return) Valves	One-way valves preclude backflow by blocking the flow of material up the wash lines Use of Hansen flexible (self-seal) couplings would incorporate this feature Active protection	Valves will need to be tested and maintained to assure operability	No	No
Administrative Controls	Reduces the likelihood of inadvertently connecting two or more tanks to the same supply line Mitigates the total dose received by the worker by reducing the exposure time	Depends on adherence to procedures	Yes-if not the primary element of the control strategy	Yes
Siphon Breaks	Siphon breaks prevent a siphon by venting the wash line during the initiation of a backflow Active protection Simple and reliable Can be located out-of-cell	Some siphon breaks will need to be tested and maintained to assure operability Worker may be exposed during testing and maintenance (Fault Condition)	Yes	No

Table 3.9-1. Initial Evaluation

Control	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Shielding	Mitigates the total dose received by workers by limiting the amount of radiation exposure	Does not prevent an actual backflow event Added expense of shielding lines inside and outside of wash cabinets in the operations area	No	No
Automated Washing Systems	Reduces the risk to the worker during a backflow event by increasing the distance between the worker and the affected wash cabinet Could allow the use of submerged wash lines by incorporating a positive blowout feature This would empty the line of wash liquor on completion of washing by blowing the line clear with compressed air	Added cost of designing and fabricating an automated washing system More components that may potentially fail Additional maintenance requirements may increase overall worker doses System reliability unknown. Effectiveness and practicability not known Development work would be required	Yes	No

The following controls remained to be considered in formulation of the control strategy to be adopted:

- Barometric Head Protection
- Administrative Controls
- Provision of 3-Way Valves
- Wash rings above Maximum Operating Liquor Level of Tank

3.9.3.2.2. Engineering Screening (Step 2)

The preferred strategy was then developed through an engineering evaluation of the alternatives. This took account of the following considerations to ensure a comprehensive approach in the context of other hazards and the overall design.

- Introduction of secondary hazards
- Impact on safety features provided to protect against other hazards
- Impact of other hazards upon the control strategy
- Robustness to other fault conditions and environments (including seismic and other design basis events)
- Passive or active, and if active, automatic or administrative/procedural – order of preference
- Robustness of any administrative controls required
- Cost
- Operability
- Maintainability
- Ease of justification (e.g., consistency with proven technology)

The considerations are presented in Table 3.9-2.

Table 3.9-2. Engineering Evaluation

Criterion	Barometric Head Protection	Wash Line and Manifold Venting (3-Way Valves)	Administrative Controls	Wash Rings Above Liquor
Introduction of Secondary Hazards	None	None significant	None	None
Impact on Safety Features Provided to Protect against Other Hazards	None	None	None	None
Impact of Other Hazards upon the Control Strategy	None	None – simple change from 2-way to 3-way valve; general arrangement remains unchanged	None	None
Robustness to Other Fault Conditions and Environments	Passive control, resistant to other fault conditions	Slight increase in potential for valve sticking and misalignment	Dependent on operator training	Potential for blockage
Passive or Active	Passive	Active	Active and dependent on procedural compliance	Passive
Robustness of any Administrative Controls Required	Very robust; none required	Very simple operating and maintenance requirements	Procedure requires no significant, complex or onerous work steps	Not applicable – piping arrangement only
Cost	Possible significant cost impact, depending upon cell layouts	Minor – valve arrangement essentially unchanged	The cost of developing procedures will not be significant since procedures will already be required to operate wash equipment and ensure worker familiarity with facility alarms	Simple arrangement required Cost expected to be minor
Operability	Proven industry practice	Good	Proven industry practice	Proven industry practice
Maintainability	Proven industry practice	Good – Located in out-of-cell area (wash cabinet)	Proven industry practice	Proven industry practice
Ease of Justification	Proven industry practice	Proven industry practice	Proven industry practice	Proven industry practice

3.9.3.2.3. Control Strategy Selected

In selecting a control strategy there is a requirement to emphasize prevention over mitigation, passive over active, and automatic over procedural.

The preferred control strategy is as follows:

- Barometric head arrangement. The design safety feature is the vertical distance (>10 m) of the piping between the top of V24007 and the wash cabinet.

- The V24007 wash rings should not be submerged. The design safety feature is the positioning of the wash rings above the expected maximum liquor level in V24007.

Barometric head protection is passive, and does not rely on mechanical or worker intervention. Backflow due to siphoning is not a credible event for a design incorporating barometric head protection. The primary element of the control strategy, location of the wash cabinet to ensure a barometric head, eliminates the hazard with simple and reliable passive protection.

Not submerging the wash ring provides an additional passive barrier for most conditions. It should be noted that it may not be possible to adopt this passive approach for all vessels. In these circumstances, the following protection should be considered with either or both of the above passive elements.
(i) Provision of 3-way venting valves
(ii) Administrative controls

Whilst not offering any protection against the siphon event discussed in this example, there are several other features of wash cabinet design that will be incorporated into the cabinet serving vessel V24007. These include:

(iii) Loop seals on the wash lines
(iv) C3 ventilation provision
(v) The cabinet will be designed to provide confinement and draining for any liquor spillage that may occur
(vi) Segregation of the cabinet environment from the operating area
(vii) Administrative controls for the operation and maintenance of the cabinet

All of these features (i-vii) protect against back flow of activity from the vessel environment to the operating area. Typical safety functions and Design Safety Features are discussed more fully in Category I, Section 2.1.7. They are not however discussed further in this report.

Area radiological monitoring to provide audible and visual warning of abnormal activity in air or gamma radiation levels in the operating area will mitigate against this event or any other. It will be provided, de facto, but since not relied upon in this example it has not been called up as an important to safety component in the subsequent discussion of this specific control strategy.

3.9.3.3. Structures, Systems, and Components that Implement the Control Strategy

The following SSCs implement a control strategy that eliminates the major hazard of bulk liquor siphoning.

Piping (Passive). Its safety function is to maintain process liquor (and activity) confinement within vessel V24007 and the process cell. Its DSF is its arrangement so that it ensures >10 m of vertical height between the wash cabinet and the process vessel.

NOT Submerged Wash Ring - It's safety function is to prevent bulk process liquor entering the wash line and the DSF is that it is above the vessel overflow which is the maximum credible liquor level.

There are no important to safety SSCs in support systems required to implement this control strategy.

3.9.4. Safety Standards and Requirements

3.9.4.1. Reliability Targets

The unmitigated consequences of the siphon event were estimated to give rise to a SL-1 hazard (Section 3.9.2.3) with a frequency of 3.0×10^{-2}/y (Section 3.9.2.4). Since the target frequency of a SL-1 hazard is $< 1.0 \times 10^{-6}$/y, the reliability target for the control strategy is a probability of failure on demand (pfd) of not greater than 3.3×10^{-5}.

Use of a barometric head arrangement will deterministically eliminate the SL-1 hazard; hence, a reliability target is not quoted. The composite control strategy includes active SSCs that protect against lesser consequence events.

3.9.4.2. Performance Requirements

The requirement is to locate the wash cabinet ≥ 10 m above the vessel (V24007) top dished end and ensure that the wash ring is not submerged by positioning above the vessel overflow.

3.9.4.3. Administrative Measures

Operating instructions will be written to show the sequence of steps for addition of wash liquor through the wash lines to vessel V24007. They will address operating the valves in the wash cabinet, monitoring the wash liquor flow into vessel V24007 and isolating the systems after completion of the wash. These instructions, supported by suitable operator training, will help ensure that wash cabinet (C3) confinement is maintained and that washing operations do not allow a backflow of activity from the process cell into the wash cabinet. There will also be operating instructions on the care and maintenance of loop seals so as to preserve their integrity. **Operational Assumptions**.

The key steps associated with the plant cabinet operations include:

- Authorization of operation to proceed
- Confirming valve status of cabinet is correct
- Monitoring vessel levels during the wash cycle
- Confirmation that wash finished status is acceptable
- Response to activity in air or area gamma monitors

Operators will be trained to identify, diagnose and respond to abnormal operating conditions. Plant information will be relayed to the operators in such a manner to aid the operator in performing this duty. Typically any deviation of the process from its normal operating condition will generate an alarm appropriate to its importance. This alarm will annunciate at the operators workstation or locally within facility. Operational procedures will detail the:

- Actions the operator must perform
- Initators
- Follow-up actions

3.9.4.4. Administrative Standards

Operation of the TWRS Facilities shall be conducted in accordance with proven practices from BNFL operations in the UK and the US. Arrangements will be in place to maintain and demonstrate compliance with all Safety Criterion detailed within the authorization basis.

Administrative arrangements will provide the framework for how facility operations will be conducted for all modes of operation, be that normal, maintenance or emergency preparedness.

The conduct of operation guidelines will be generated by the tailored application of appropriate sections of the following stardards:

IAEA 50-C-0: Code on the Safety of Nuclear Power Plants Operation
DOE order 5480.19 “Conduct of Operations Requirements for DOE facilities”.
DOE order 4330.4B “Guidelines for the Conduct of Maintenance at DOE Nuclear Facilities”.
“Appropriate standards” from the Institute for Nuclear power Operations.

This framework of conduct will be implemented through:

Management and organizational structure.

- Documents, records and certification, including response to abnormal operating conditions, key compliance recording and archiving.

- Structured training programs for all personnel, tailored to their roles and responsibility.

- Emergency preparedness implemented by having an emergency response structure, training, exercises and procedures.

- Incident reporting araangements

- Safety documentation hierarchy, with appropriate flow down of information into operational documentation. All safety implications will be clearly identifiable within the operational procedures.

- Quality assurance

- Arrangements for the examination, inspection, maintenance and testing of all ITS equipment.

- Labeling of ITS equipment clearly on the facility.

3.9.4.5. Design Standards

The following design Standards will implement the control strategy:

K70DG697 Design Guide for Plant Wash Operations

This document provides guidance in the design of vessel, cell and cladding, and bulge plant wash operations; and includes methods for sizing and positioning vessel wash rings, cell and bulge spray bars, and hydraulic seal heights.

K70DG633 Design Guide for Plant Wash Cabinets

This guide specifies cabinet applications and identifies technical design requirements for standard plant wash cabinets, which includes the configuration of internals (valves and pipes) and ventilation.

NF0105/1 Glove Boxes – Specification for Fabrication of Shielded and Unshielded Steel Type

This standard specifies the manufacturing, quality assurance, testing, inspection, assembly, and delivery requirements for fabricated unshielded and shielded glove boxes.

NF0165/1 (AECP 59) Shielded and Unshielded Gloveboxes for 'Hands On' Operation-Code of Practice

This Code of Practice contains recommendations that are appropriate to the design of glove boxes, both shielded and unshielded, for contained systems using manual operations or requiring manual intervention. It includes both operational and safety basic design principles, recommendations on constructional materials and types of fabrication and facilities.

It includes the supporting services necessary for glove box functioning. These include electrical and ventilation requirements, hydraulic, pneumatic and drainage needs and process control instrumentation.

ASME B31.3 Process Piping

The ASME B31.3 Code for Process Piping is an American National Standard that provides the necessary requirements for the safe design and construction of pressure piping used in chemical process plants. Category M fluid service design requirements are selected for the process liquor back flow because there is a potential for personnel exposure and because that exposure is hazardous to personnel.

The following standards referenced in this report are not contained in the SRD:

K70DG697 Design guide for plant wash operations
K70DG633 Design guide for plant wash cabinets
NF0105/1 Gloveboxes – specification for fabrication of shielded and unshielded steel type
NF0165/1 (AECP 59) Shielded and unshielded gloveboxes for "hands on" operation – Code of Practice

3.9.5. Control Strategy Assessment

3.9.5.1. Performance Against Common Cause and Common Mode Effects

3.9.5.1.1. Natural Phenomena

No NPH were found to influence the frequency of the event.

3.9.5.1.2. Man-Made Hazards

No man-made external events were found to influence the frequency of the event.

3.9.5.1.3. Common Cause and Mode Effects

Section 3.9.2.5 assessed the contribution of loss of power to initiating a siphoning event. The control strategy selected is insensitive to power failure. No common cause or common mode effects have currently been identified that are likely to be significant contributors either to the frequency or the consequences of a siphon backflow event. Further consideration will be given to the potential for common cause and common mode effects during the hazard identification and evaluation work that will proceed in tandem with the detailed design. **Open Issue.**

3.9.5.2. Comparison with Top-Level Principles

As a final test, the preferred control strategy is evaluated against a set of relevant top-level radiological, nuclear and process safety standards and principles (DOE-RL 1998).

3.9.5.2.1. Defense in Depth (DOE/RL-96-0006, 4.1.1)

Defense in depth is one of the general radiological and nuclear safety principles in DOE/RL-96-0006. SRD Volume II, Appendix B contains the BNFL *Implementing Standard for Defense in Depth*. This Implementing Standard governs application of the defense in depth principle on the TWRS-P project.

To satisfy the application of defense in depth, the Implementing Standard requires that the elements of the control strategy must ensure "…that no one level of protection is completely relied upon to ensure safe operation. This strategy provides multiple levels of protection to prevent or mitigate an unintended release of radioactive material to the environment."

DOE/RL-96-0006 formulates the defense in depth principle in terms of the following six sub-principles:

- Defense in depth
- Prevention
- Control
- Mitigation
- Automatic Systems
- Human Aspects.

SRD Volume II, Appendix B contains the BNFL Implementing Standard for Defense in Depth. This implementing standard governs application of the defense in depth principle on the TWRS-P project and addresses each of the six sub-principles in DOE/RL-96-0006. The following paragraphs describe application of the Implementing Standard for Defense in Depth to the control strategy for backflow.

1. Defense in Depth (DOE/RL-96-0006, 4.1.1.1)

DOE/RL-96-0006, Section 4.1.1.1 requires the following:

> *"To compensate for potential human and mechanical failures, a defense-in-depth strategy should be applied to the facility commensurate with the hazards such that assured safety is vested in multiple, independent safety provisions, not one of which is to be relied upon excessively to protect the public, the workers, or the environment. This strategy should be applied to the design and operation of the facility." (DOE/RL-96-0006, Section 4.1.1.1)*

Section 3.0 of the BNFL Implementing Standard for Defense in Depth addresses this aspect of the defense in depth principle specifically. For SL-1 events, Section 3.0 of the *Implementing Standard for Defense in Depth* requires:

- Two or more independent physical barriers to confine the radioactive material
- Application of the single failure criterion
- A target frequency of $< 1.0 \times 10^{-6}$/y for the SL-1 consequences

The control strategy provides two barriers against the hazard of direct radiation shine arising from siphoning of liquor out of Vessel V24007 into the wash supply line in the operating area. Both barriers are passive. The first is the barometric head and the second is not submerging the wash ring in the vessel.

The Implementation Standard requires application of the single failure criterion to active SSCs. The single failure criterion requires that, given an initiating event, the control strategy must be able to tolerate a single active failure in any active component in the short term. The single passive failure is to be a mechanistic failure (for example, pump seal leakage); the single passive failure is not a deterministic failure (for example, a pipe break).

The control strategy is purely passive and precludes the possibility of backflow. Therefore, the control strategy satisfies the single failure criterion.

The analysis in Sections 3.9.5.3, 3.9.5.4, and 3.9.5.6 indicates that the control strategy precludes backflow. Therefore, the frequency of any significant consequence from backflow is negligible. This satisfies the Implementing Standard target frequency for SL-1 consequences.

Based on the results of the frequency estimate, the control strategy meets the target frequency. Also, the frequency estimates indicate that the control strategy does not place excessive reliance on any single element to achieve this result.

2. Prevention (DOE/RL-96-0006, 4.1.1.2)

The elements of prevention include a conservative design, minimizing material at risk; provision of physical barriers with the engineering (SSCs) backed up by administrative controls. The proposed control strategy incorporates a conservative, well proven design that includes physical barriers, simple and reliable SSCs backed up by operating instructions.

3. Control (DOE/RL-96-0006, 4.1.1.3)

The elements of control include the control of normal operations so that facility and system parameters remain within specified operating ranges and the frequency of demands placed on SSCs for hazard prevention and mitigation is small. Washout of V24007 will be a normal event that is to be carried out at a frequency defined by the operations program assumed to be annually. **Operating Assumption**. In preparation of washing, V24007 will be emptied to low level thus removing the majority of the process material. The operating instructions will require monitoring of the tank liquor levels during washing process. The provision of the barometric head arrangement ensures that no bulk liquor can flow back from the vessel into the wash cabinet pipework under any variation in the washing operation. Administrative controls (operating instructions) will ensure that the loop seal and wash cabinet integrities are maintained and that venting of the wash line takes place at the correct time.

4. Mitigation (DOE/RL-96-0006, 4.1.1.4)

The purpose of mitigation is to ensure reduction of consequences from potential hazards and hazardous situations. The control strategy employs multiple independent barriers. Use of the barometric head arrangement ensures robustness if other barriers are challenged since the siphoning event cannot occur. If barriers are compromised (fault condition), then the presence of the area radiological monitoring and cascade ventilation systems will ensure that potential doses to workers are minimized from any ensuing hazardous situation.

5. Automatic Systems (DOE/RL-96-0006, 4.1.1.5)

Automatic systems shall be provided to prevent the facility from entering into or remaining within an unsafe regime that may lead to the potential for a radioactive or hazardous material release; i.e., loss of confinement. The barometric head arrangement is a simple, passive system that will operate to confine bulk radioactive material without operator intervention.

6. Human Aspects (DOE/RL-96-0006, 4.1.1.6)

The facility design should take account of human factors, elements of which include the QA program, administrative controls, safety reviews, TSRs, worker qualification and training and the establishment of a safety/quality program. Operating instructions on how to use the wash lines to V24007 are to be developed. The instructions will emphasize the need to maintain the barriers in place (adequate use and isolation of valves and couplings, operation of the wash liquor so as to maintain the loop seal, preservation of the wash cabinet integrity) throughout and after a V24007 wash. **Operational Assumption.** Operating instructions so developed will be subject to internal review and regular checks to ensure their quality is maintained and that the appropriate safety aspects of vessel washing are and continue to be addressed.

Since the Severity Level for the backflow hazard is SL-1, per Section 2.6.2 of the *Implementing Standard for Defense in Depth*, the control strategy must be reviewed against the human factors engineering criteria in IEEE Std. 1023-1988, 6.1.1, as tailored by the *Implementing Standard*. **Open Issue**.

3.9.5.2.2. Operating Experience and Safety Research (DOE/RL-96-0006, 4.1.2.4)

Section 3.9.1.3 of this report details some of the operating experience obtained with Sellafield nuclear facilities. The use of out-of-cell cell wash cabinets and wash lines to supply wash water to in-cell process vessels is a well-proven technique. Hazard identification and assessment studies and operating experience have indicated the potential for bulk process liquor ingress to the wash cabinet pipework by way of the mechanisms of siphoning and back diffusion. Operating experience has shown that activity from wash lines, or other lines connected to a process vessel, can migrate to the wash (or service) cabinet pipework through a flooded line. The use of a barometric head arrangement is used where facility layout permits. The use of vented (3-way) valves and loop seals is used to prevent any backflow event.

3.9.5.2.3. Proven Engineering Practices (DOE/RL-96-0006, 4.2.2.1)

Based on the operating experience as mentioned in the above paragraph, the use of the barometric head arrangement is the preferred element of a control strategy to control the potential for siphoning or other potential backflow events. It has been employed widely at Sellafield facilities where facility layout permits and is always backed up with loop seals and valve venting arrangements. The standards referenced in Section 3.9.4.5 require the inclusion of loop seals and valve venting on wash or service lines which originate out-of-cell and are connected to in-cell process vessels.

3.9.5.2.4. Common Mode/Common Cause Failure (DOE/RL-96-0006, 4.2.2.2)

Section 3.9.2.5 addresses common cause and common mode failure. No external impact event or NPH was seen as having the potential to initiate a siphoning or backflow event if it occurred coincident with tank washing. Hence, the effects on the control strategy need not be considered further. Loss of power was considered as a potential initiator of the hazard (assuming that tank washing was taking place and that loss of power would fail-close the main wash-liquor manifold valve). However, the frequency of the coincident event, assessed in Section 3.9.2.5, was low in comparison with the operator error alone as the initiator. It was not considered further for this example. Part of the detailed hazard identification and assessment work accompanying the Part B1 detailed design development will explicitly address the potential failures resulting from common cause or common mode events.

3.9.5.2.5. Safety System Design and Qualification (DOE/RL-96-0006, 4.2.2.3)

The SSCs associated with the control strategy are to be designed with consideration for the intended safety function (see Table 3.9-3). The SSCs are all well-proven technology which has been utilized extensively at other, similar facilities.

3.9.5.2.6. Radiation Protection Features (DOE/RL-96-0006, 4.2.3.2)

The provision of a barometric head arrangement ensures that bulk process liquor and hence, high activity cannot reach out-of-cell. Activity migration through a flooded line or airborne backflow is prevented by the valve venting arrangements and loop seals. (SSCs that require administrative controls for their correct operation.) Additionally, the control strategy lists area (activity-in-air and gamma) radiological monitoring and the cascade properties of the C2/C3/C5 ventilation system as those elements which reduce potential radiation exposure to ALARA during normal operations and mitigate the potential exposures to workers from a siphon or other activity backflow fault condition. The control strategy has been subjected to an ALARA design review which concluded that the selected strategy has no adverse ALARA impact (Pisarcik 1999d).

3.9.5.2.7. Deactivation, Decontamination and Decommissioning (DOE/RL-96-0006, 4.2.3.3)

The purpose of tank wash operations utilizing a suitable wash liquor is to reduce the activity inventory of the tank at the end of a process campaign (prior to an engineering outage) and to prevent chronic buildup of solids and activity within the tank. This tank washing process is a vital component of the deactivation program. The removal of bulk activity by washing, and the prevention of chronic activity buildup by regular washing during the facility life, will ensure that the generation of radioactive waste from tank deactivation will be kept to a minimum. The proposed control strategy will ensure the effectiveness of tank washing throughout the facility life and thus aid final deactivation.

3.9.5.2.8. Emergency Preparedness – Support Facilities (DOE/RL-96-0006, 4.2.4)

The strategy has no anticipated impact on the control room or emergency response center that may have to be manned after an event.

3.9.5.2.9. Inherence/Passive Safety Characteristics (DOE/RL-96-0006, 4.2.5)

The control strategy employs simple, reliable and passive protection as its primary element. The use of the barometric head arrangement is simply a function of the length of vertical pipework (>10 m) between the wash cabinet and the top of vessel V24007. Elements, additional to the control strategy, loop seals and valve arrangements, are also simple and well-proven technology. Although they are active protection, they are amenable to simple maintenance and testing regimes. All of the valves are located out-of-cell in the wash cabinet where they are easily inspected and maintained. The loop seal is a hydraulic seal; its continued performance can be monitored by a simple regime of regularly refilling the loop with liquor. **Operating Assumption.**

3.9.5.2.10. Human Error (DOE/RL-96-0006, 4.2.6.1)

The performance of the primary element of the control strategy is independent of the operator. The potential for human error in applying the other elements of the control strategy will be minimized by a robust set of operating instructions for tank washing backed up by suitable worker training. The potential for human error as a contributor to fault conditions involving backflow of activity from a process cell to an out-of-cell environment is to be considered as part of the hazard identification and assessment work accompanying the detailed design development in Part B-1 of the contract. **Open Issue.**

3.9.5.2.11. Instrumentation and Control Design (DOE/RL-96-0006, 4.2.6.2)

Instrumentation is not required to ensure the operability of barometric head protection. Instrumentation to monitor washing operations (e.g., tank level indicators, flow gauges, DSFs) will be available at the wash cabinets to monitor in-progress washes.

3.9.5.2.12. Safety Status (DOE/RL-96-0006, 4.2.6.3)

Control room operators will have access to those important V24007 tank parameters (wash liquor flow rates, V24007 liquor level, area radiological monitoring and the C2/C3/C5 ventilation system performance) that can be monitored during tank washing operations.

3.9.5.2.13. Reliability (DOE/RL-96-0006, 4.2.7.1)

The overall reliability requirement of the control strategy has been assessed as 3.3×10^{-5} probability of failure on demand. Although this figure is not applicable to the primary element of the control strategy (i.e., provision of a barometric head), it is quoted for the other elements which add robustness and defense in depth, resulting in a control strategy that not only addresses the potential for bulk process liquor ingress to the out-of-cell pipework. Additionally, it addresses lower consequence events such as activity migration by diffusion. A reliability figure is not applicable to the provision of a barometric head since this is simply the function of a vertical length of pipework (>10 m) between the wash cabinet and the top of V24007.

3.9.5.2.14. Availability, Maintainability, and Inspectability (DOE/RL-96-0006, 4.2.7.2)

SSCs will be subject to a program of scheduled maintenance and testing to be defined as part of the detailed design and operational requirements. **Open Issue.**

3.9.5.2.15. Pre-Operational Testing (DOE/RL-96-0006, 4.2.8)

The control strategy is amenable to pre-operational testing. The primary elements of the control strategy, provision of a barometric head tested by confirmation of the correctness of the detailed isometric diagrams which show the relative heights and distances between facility equipment. Other elements of the control strategy (valve and loop seal operation) will be tested as part of start up testing of the efficiency of the installed tank wash system. This will also allow testing of the effectiveness of the operating instructions and facility worker training.

3.9.5.3. Mitigated Consequences

Backflow due to siphoning is not a credible event in a design incorporating barometric head protection; therefore there are no mitigated consequences associated with this event.

3.9.5.4. Frequency of the Mitigated Event

Backflow due to siphoning is not a credible event in a design incorporating barometric head protection; therefore there are not releases associated with this event.

3.9.5.5. Consequences with Failure of the Control Strategy (Including Mitigation)

Barometric head protection is an inherent, deterministic safety feature that is not subject to failure. Therefore, there are no consequences associated with a failure of the control.

3.9.5.6. Frequency of Control Strategy Failure

Backflow due to siphoning is not a credible event in a design incorporating barometric head protection.

3.9.6. Conclusions and Open Issues

3.9.6.1. Conclusions

Locating the wash cabinets at a level above the process vessels such that there is a barometric head (>10 m vertical distance) precludes backflow into the cabinets by siphoning. With this design, siphoning is not a credible event either in normal or abnormal conditions. However, backflow can occur due to reasons other than siphoning. For example, it may be possible to overfill a tank with process material, wash water, or cooling water (if the cooling coil fails). In these cases, material may be forced out of the tank and into a wash cabinet, or migrate out of the tank and into a wash cabinet. These events will be evaluated as part of the ongoing Integrated Safety Management process. **Open Issue**.

The control strategy is summarized in Table 3.9-3.

3.9.6.2. Open Issues

A number of open issues have been identified for further investigation and resolution as part of design development.

1. **Columns vs. Tanks**. Ten of the 53 vessels in the pretreatment facility are columns. Columns are washed with spray nozzles. Tanks are washed with wash rings. This example assumes that the potential for backflow is the same in columns and tanks, and treats the columns as if they are tanks. Evaluation is necessary to determine if columns represent a unique backflow potential.

2. **Wash Cabinet and Wash Line Elevations.** Preliminary plant layout drawing SK-W-375 PT-PL00007, Rev. A, indicates that most wash cabinets will have sufficient elevation for barometric head protection. Further evaluation is necessary to determine those wash cabinets that, on the basis of facility layout or other design/operational reasons cannot be located above a barometric head in relation to the process vessels which they serve. For these cabinets, siphoning is only credible if their wash lines are submerged within the process vessel.

If there are wash cabinets which are both:

- located less than a barometric head above the process vessels which they serve, and
- some or all of the wash lines to those vessels are submerged,

then further evaluation of the composite control strategy will be necessary, as further design detail becomes available in order that siphoning is prevented.

3. **Consequences of Overfilling.** It may be possible to overfill a tank and force material out of the tank and into a wash cabinet, or allow material to migrate out of the tank and into a wash cabinet. In this case, the event is due to a mechanism other than siphoning and has not been explicitly evaluated in this report.

4. **Other Backflow Events.** Evaluation is necessary to determine if additional controls are necessary or are in-place to prevent and/or mitigate other types of backflow events and for consideration of potential worker contamination as related to this example, future evaluations will also reconsider loss of power, reliability of area radiological monitoring equipment.

5. **Scheduled Maintenance.** Development of a program of scheduled maintenance and testing.

6. **Human Factors Review.** The control strategy must be reviewed against the human factors engineering criteria in IEEE Std 1023-1988, 6.11, as tailored by the Implementing Std.

In addition to the open issues listed above, various design and operational assumptions are highlighted in the report. Their continuing validity will be monitored through design development.

Table 3.9-3. Control Strategy Summary

Hazard Description: Siphoning of Process Liquor from Cs Storage Vessel V24007 to its Wash Cabinet – Activity Migration				**Initiator:** Operator Error	
Selected Control Strategy	**Important-to-Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
Barometric Head Protection Non-submerged Wash Ring	Pipework	To maintain process liquor confinement within V24007	Vertical length of piping above the top of V24007	Cell and operating area layouts will allow the provision of a barometric head (> 10 m vertical distance)	

References

BNFL Inc., 1997a, *Hazard Analysis Report*, BNFL-5193-HAR-01 Rev. 0, BNFL Inc., Richland, Washington.

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[a] For access to these documents, contact the Design Safety Features Point-of-Contract through the office of Safety and Regulatory Programs, TWRS-P, Richland, Washington.
[b] Copies of these references accompany this deliverable.

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Figure 3.9-1. Wash Cabinet Arrangement